



CMCLA 0102 PUS

08466219

A METHOD AND SYSTEM FOR MONITORING A PARAMETER OF A VEHICLE TIRE

Technical Field

5 The present invention relates to a method and system for monitoring a parameter of a vehicle tire and more particularly to tire temperature and pressure monitoring systems for a vehicle.

Background Art

10 Motor vehicles which are supported by inflatable tires generally have a desired inflation pressure. The improper inflation of a tire can lead to poor gas mileage, ^{increased} increase tire wear and to a loss of handling ability, particularly during emergency braking and maneuvering conditions.

15 Unfortunately, many motor vehicle operators do not take the time to monitor the pressure in their tires. Once the tires are inflated, pressure generally is not measured unless a tire is visibly under-inflated or tire inflation has caused a defect in vehicle
20 handling which is apparent to the operator. By this point, the tire has already been operated in a state of improper inflation.

25 Prior art devices have attempted to resolve this problem by providing an automatic tire pressure monitoring system for monitoring the pressure within the tires and providing an indication to the vehicle operator when one or more of the tires reaches a

condition of improper inflation. One class of such tire pressure monitoring systems includes a tire pressure sensing apparatus as well as a transmitter contained within each of the tires. The tire pressure is
5 monitored and transmitted to a central receiving unit which in turn provides an indication to the vehicle operator.

The use of airwave communications between the transmitter and receiver creates a host of problems.
10 With the transmitting unit wholly contained within a particular tire, relatively weak signals are transmitted since the transmitter must rely upon a battery as a source of power. Further, the metallic configuration of a vehicle frame and body is not generally conducive to
15 the transmission of signals from the wheel wells of a vehicle to a centrally located monitor. Further, as a wheel rotates, a transmitted tire pressure signal is subjected to a doppler shift based upon this rotation if the transmitter antenna is not oriented in a fashion
20 such that its center of mass lies along the axis of rotation of the wheel.

The reliance upon a battery in these prior art systems provides a further problem, that of limited battery life. If a battery is installed in a tire
25 pressure monitoring system within a tire, that battery will require replacement at some point which could require the dismounting of the vehicle tire from the wheel. An alternate source of power for a tire pressure monitoring system is presented by U.S. Patent No.
30 4,160,234 to Karbo, et al. This patent discloses a self-powered tire condition indicator system in which a plurality of wheel mounted transmitting assemblies

communicate by radio frequency transmission to a receiver located within the operator compartment of the vehicle. Each of the transmitting assemblies generates its own transmitting power by converting the mechanical compression of a flat tire into electrical energy using a piezo-electric transducer. This system, while not requiring a battery for operation, suffers from the fact that a tire must be in a severely deflated condition to energize the unit. Thus, this system is unable to provide a monitoring of the tire pressure during conditions when the tire is properly inflated or if the tire deflation is slight.

A further problem with prior art tire pressure monitoring systems where a pressure sensor and transmitter unit is contained within a tire is that reprogramming or testing of the unit requires dismounting of the tire. This is an inconvenient and expensive process.

Prior art tire pressure monitoring systems further include monitoring of the temperature within a tire. This is important given that increased tire temperature can be indicative of underinflation or other tire defects which again could be a source of concern for a vehicle operator. These prior art systems, however, lack the ability to compare the sensed tire temperature with an ambient temperature to determine if the tire temperature is abnormal given ambient conditions.

Summary of the Invention

It is thus an object of the present invention to provide a tire pressure monitoring system which includes a reliable communication link between a plurality of sensors located within the tires of a vehicle and a central receiving unit.

A further object of the present invention is to provide a tire pressure monitoring system whereby the vehicle ground provides an electromagnetic path for RF signals between a tire pressure monitoring sensor located within a tire and a central receiving unit.

Moreover, an object of the present invention is to provide a piezo-electric power source for a sensor and transmitter unit of a tire pressure monitoring system located within a vehicle tire such that the sensor and transmitter unit are powered during normal inflation of the tire.

Furthermore, an object of the present invention is to provide a piezo-electrical power source for a sensor and transmitter unit of a tire pressure monitoring system with capacitive storage such that the sensor and transmitter unit ^{are} ~~is~~ capable of reduced functioning during periods of time that the tires are stationary.

An additional object of the present invention is to provide a communication link between a remote controller connectable to the receiver for reading and storing the various operational parameters of the receiving unit.

An object of the present invention is also to provide a communication link between a detector/transmitter unit disposed within a tire and a remote controlling unit for storing the various parameters of the detector/transmitter unit for reading the status and operational parameters of the unit and for initiating a test of the sensor.

Another object of the present invention is to provide a tire parameter monitoring system which monitors the temperature of a tire and further monitors the ambient temperature of the air surrounding a vehicle for the purposes of deriving a differential temperature measurement.

In carrying out the above objects, the present invention provides a method for monitoring a parameter of a tire for a vehicle having one or more conductive components which form ^{an} ~~a~~ electromagnetic path with first and second ends.

The method comprises the steps of generating a signal indicative of a parameter of the tire using a sensor disposed within the tire, transmitting the generated signal along the electromagnetic path by introducing the generated signal to the electromagnetic path first end, receiving a path signal at the electromagnetic path second end, the path signal being responsive to the generated signal, ^{and} ~~a~~ monitoring the tire parameter by monitoring the path signal.

In further carrying out the above objects, the present invention provides a system for monitoring a parameter of a tire for a vehicle.

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5 This system comprises a sensor, disposed within the tire, for generating a signal indicative of the parameter of the tire, an electromagnetic path being formed of a plurality of conductive components of the vehicle, the electromagnetic path having first and second ends, a transmitter, in electrical communication with the sensor and with the electromagnetic path first end, for transmitting the generated signal along the electromagnetic path, a receiver, in electrical communication with the electromagnetic path second end, for receiving a path signal at the electromagnetic path second end, the path signal being responsive to the generating signal, ^{and} a monitor, in electrical communication with the receiver, for monitoring the tire parameter by monitoring the path signal.

Moreover, in carrying out the above objects, the present invention provides a system for monitoring a parameter of a tire for a vehicle.

20 The system comprises a sensor, disposed within the tire, for generating a signal indicative of the pressure of the tire, an electromagnetic path being formed of a plurality of conductive components of the vehicle including a wheel rim for the tire, one or more wheel bearings for rotatably supporting the wheel on a non-rotating member, and the non-rotating member, the electromagnetic path having first and second ends, a transmitter, in electrical communication with the sensor and with the electromagnetic path first end, for transmitting the generated signal along the electromagnetic path, a receiver, in electrical communication with the electromagnetic path second end, for receiving a path signal at the electromagnetic path

second end, the path signal being responsive to the generating signal, ^{and} a monitor, in electrical communication with the receiver, for monitoring the tire parameter by monitoring the path signal.

5 In carrying out the above objects, the present invention also provides a system for monitoring the status of a parameter of a tire for a vehicle.

The system comprises a sensor, disposed within the tire, for generating a signal indicative of the parameter of the tire, a processor, in electrical communication with the sensor for determining the status of the tire parameter by comparing the tire parameter to a selected threshold, a transmitter, in electrical communication with the processor for transmitting a status signal indicative of the tire parameter status along a first communications link, a monitor, in communication with the first communications link, for monitoring the status of the tire parameter, a communication unit in electrical communication with the processor having a first receiver for receiving a processor control command, ^{and} a remote controller, positionable for electrical communication with the communication unit along a second communications link, for initiating the processor control command.

25 In addition, in carrying out the above objects, the present invention provides a system for monitoring a parameter of a tire for a vehicle.

The system comprises a sensor, disposed within the tire, for generating a signal indicative of the parameter of the tire, a transmitter, in electrical

communication with the sensor for transmitting the generated signal along a first communications link, a monitor, in communication with the first communications link, for monitoring the tire parameter by receiving the generated signal, a processor, in electrical communication with the monitor for determining an alarm condition based upon the monitored tire parameter, a communication unit in electrical communication with the processor having a first receiver for receiving a processor control command, ^{and} a remote controller, positionable for electrical communication with the communication unit along a second communications link, for initiating the processor control command.

In carrying out the above objects, the present invention further provides a system for monitoring a parameter of an inflatable tire for a vehicle.

The system comprises a sensor, disposed within the tire, for generating a signal indicative of the parameter of the tire, a transmitter, in electrical communication with the sensor for transmitting the generated signal along a first communications link, a piezo-electric element, for supplying power to the transmitter independent of the inflation pressure of the tire, ^{and} a monitor, in communication with the first communications link, for monitoring the tire parameter by receiving the generated signal.

In carrying out the above objects, the present invention moreover provides a system for monitoring a temperature of a tire for a vehicle.

5 The system comprises a first temperature
sensor, disposed within the tire, for generating a
signal indicative of the temperature of the tire, a
transmitter, in electrical communication with the sensor
for transmitting the tire temperature signal along a
first communications link, a second temperature sensor,
associated with the vehicle, for generating a signal
indicative of the ambient temperature of the air
surrounding the vehicle, ^{and} a monitor, in communication
10 with the first communications link and the second
temperature sensor, for determining a temperature
parameter in dependence upon the tire temperature signal
and the ambient temperature signal.

15 In carrying out the above objects, the present
invention additionally provides a method for providing
a user interface for a tire parameter monitoring system
for a plurality of tires of a vehicle, the monitoring
system having an alarm state triggerable by a parameter
fault in any one of the tires.

20 The method comprises a user interface for a
tire parameter monitoring system for a plurality of
tires of a vehicle, the monitoring system having ^{an} ~~a~~ alarm
state triggerable by a parameter fault in any one of the
tires, the method comprising the steps of displaying, in
25 alphanumeric format, an indication of the occurrence of
an alarm state which identifies a particular tire which
is the source of the alarm state, receiving a first
indication from the user to terminate the alarm
condition, terminating the alarm display in response to
30 the receipt of the first user indication, receiving a
second indication from the user to provide further
information on the source tire, ^{and} ~~and~~ displaying, in

alphanumeric format, the tire parameter corresponding to the source tire in response to the receipt of the second user indication.

Brief Description of the Drawings

5 FIGURE 1 presents a block diagram representation of the tire parameter monitoring system of one embodiment of the present invention;

10 FIGURE 2 presents a block diagram representation of the detector/transmitter unit of the tire pressure monitoring system of one embodiment of the present invention;

15 FIGURE 3 presents a block diagram representation of one embodiment of the receiver/user interface unit of the tire pressure monitoring system of the present invention;

 FIGURE 4 presents a block diagram representation of one embodiment of the communication link used in the tire pressure monitoring system of the present invention;

20 FIGURE 5 presents a pictorial/schematic diagram of one embodiment of the receiver/user interface unit of the tire pressure monitoring system of the present invention;

25 FIGURE 6 presents a block diagram representation of one embodiment of the tire pressure monitoring system of the present invention;

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FIGURE 7 / presents a combination schematic/block diagram of one embodiment of the detector/transmitter unit of the tire parameter monitoring system of the present invention;

5 FIGURE 8 presents a block diagram of the supervisory link interface for the detector/transmitter of one embodiment of the present invention;

10 FIGURE 9A presents the use of the tire pressure monitoring system of one embodiment of the present invention in conjunction with a vehicle;

FIGURE 9B presents a representation of the location of the detector/transmitter unit within a wheel of one embodiment of the present invention;

15 FIGURE 9C presents a vertical cross-section of one embodiment of the detector/transmitter unit of the tire parameter monitoring system of the present invention;

20 FIGURE 9D presents a bottom view of one embodiment of the detector/transmitter unit of the tire parameter monitoring system of the present invention;

FIGURE 9E presents a top view of one embodiment of the detector/transmitter unit of the tire parameter monitoring unit of the present invention;

25 FIGURE 9F presents a side view of one embodiment of the detector/transmitter unit of the tire parameter monitoring system of the present invention;

FIGURE 9G presents a side view of a stud rivet for mounting detector/transmitter unit to a wheel in one embodiment of the tire parameter monitoring system of the present invention;

5 FIGURE 10 presents a pictorial lay out of the matrix keypad for the user interface of one embodiment of the tire parameter monitoring system of the present invention;

10 FIGURE 11 provides a summary of control commands for the RS232 interface of the receiver/user interface unit of one embodiment of the tire parameter monitoring system of the present invention;

15 FIGURE 12A presents a vertical cross section of a pressure sensor for use with one embodiment of the tire parameter monitoring system of the present invention;

20 FIGURE 12B presents a vertical cross section of the contact pin/brass contact configuration of the pressure monitor of one embodiment of the present invention;

 FIGURE 12C presents a bottom view of the annular lip of the plastic retainer for the pressure monitor used in one embodiment of the tire parameter monitoring system of the present invention;

25 FIGURE 12D presents a top view of the diaphragm of the pressure sensor used with one embodiment of the tire parameter monitoring system of the present invention;

FIGURE 12E presents the piezo-resistive element of the pressure sensor used with one embodiment of the tire parameter monitoring system of the present invention;

5 FIGURE 13 presents the pressure-resistance characteristic of the piezo-resistive pressure sensor used in one embodiment of the tire parameter monitoring system of the present invention;

10 FIGURES 14A-14F present a combination flow chart representation and pictorial representation of the user interface/display functions of the user interface of one embodiment of the tire parameter monitoring system of the present invention;

15 FIGURE 15 presents a block diagram representation of the overall communications path of one embodiment of the present invention;

 FIGURE 16 presents a schematic representation of the connection of a repeater of one embodiment of the present invention;

20 FIGURE 17 presents a perspective view of the transmitter/detector unit of one embodiment of the present invention;

25 FIGURE 18A presents a top view of the receiver/user interface unit of one embodiment of the present invention;

FIGURE 18B presents a side view of the receiver/user interface unit of one embodiment of the present invention;

FIGURE 19 presents a representation of the pulsetrain used for communication in one embodiment of the present invention;;

FIGURE 20A presents the Manchester code format used for communication in one embodiment of the present invention; and

FIGURE 20B presents the frame format used for communication in one embodiment of the present invention.

Best Mode For Carrying Out The Invention

Turning now to Figure 1, a block diagram of one embodiment of the tire pressure monitoring system of the present invention is shown. In broadest terms, transmitter detector unit 10 monitors the pressure and temperature ^{within} a tire of a wheeled vehicle and transmits a signal representative of the pressure and temperature via link 12 to receiver user interface unit 14. Detector/transmitter unit 10 consists of a pressure sensor 16 and a temperature sensor 18 located in proximity to a tire so as to generate electrical signals corresponding to the tire pressure and temperature for input to detector 20. Detector 20 processes these electrical signals and communicates with transmitter 22 which broadcasts a signal representative of at least the pressure within the tire over link 12.

The user interface/receiver unit 14 consists of receiver unit 24 which accepts the electrical signal from transmitter 22 over link 12 and communicates with a user via user interface 26. In the preferred embodiment, the user interface 26 comprises an LCD display unit for displaying to the user the sensed pressure and/or temperature within the tire.

Turning now to Figure 2, a more comprehensive block diagram of detector/transmitter unit 10 is presented. Temperature sensor 34 and pressure sensor 32 are driven by function generator 30 which emits a periodic signal to each sensor. Sensors 32 and 34 are designed to vary a parameter of the periodic signal generated by function generator 30 such as the amplitude, phase, frequency, or rate of decay, as a function of the sensed variable, either temperature or pressure. Corresponding ~~to~~ detection circuits 36 and 38 are designed to detect the variation in the corresponding parameter ^{Q or A} and yield and output 37 which is proportional to temperature in the case of detection circuit 36 and yield an output 39 which is proportional to pressure in the case of detection circuit 38.

Pressure signal 39 and temperature signal 37 are input to pressure calibration unit 40 which corrects the pressure signal based upon the sensed temperature. Temperature 37 is also fed to protocol encoder 46. The pressure 41 determined by pressure calibration unit 40 is fed to threshold detector 42 which compares this pressure to one or more selected thresholds to determine if the pressure is in an appropriate operating range. In the preferred embodiment, the pressure is compared with an ideal pressure reading to determine if it is

within plus or minus three pounds per square inch of that ideal pressure. If the sensed pressure does not fall within this range, an indication signal is sent to protocol encoder 46.

5 Protocol encoder 46 operates to take the
information which has been sensed on the temperature,
pressure, and whether or not the pressure violates one
or more selected thresholds, converts this information
10 to binary bits, and prepares a block of data to be
transmitted consistent with an established protocol.
This protocol could be virtually any existing block
communications protocol or other means for performing a
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A ~~synchronous~~ asynchronous communication.

15 The individual binary bits generated by
protocol encoder 46 are sent to Manchester/FSK generator
48. This unit converts these sequential bits of infor-
mation into bi-phase level baseband transmission wave-
forms which are modulated using frequency shift keying
(FSK). This encoded signal could be then modulated
20 using a carrier frequency for radio frequency transmis-
sion. In the preferred embodiment, a traditional
carrier frequency in the range of 400 KHz is used.
However, a frequency-hop spread spectrum scheme could be
used in this regard. One with ordinary skill in the art
25 will recognize that a wide array of options exist for
implementing this communication. The present invention
should be broadly constructed to encompass the choices
of waveform encoding, modulation scheme and
communication protocol possible.

30 Turning now to Figure 3, a block diagram
representation of the receiver and user interface unit

14 is presented. The encoded data signal from the communication link is received by Manchester/FSK decoder 60. This decoder serves to convert the modulated and decoded wave forms into binary bits which are transferred to protocol decoder 62. Protocol decoder 62 strips the underlying databytes from the communicated signal and transfers these bytes as well as other indications provided by the protocol to processor 68. In addition to receiving data and indications from communication link, processor 68 is also connectably in communication with optional serial link 66 such as an RS-232, RS-432 or other similar serial communication standard. This link provides an alternate source of programming and data communication with the processor.

User interface 70 communicates with the processor to receive user input and provide output to the user in the form of displays and indications regarding the operation of the tire pressure monitoring unit. Options for this interface could include voice-activated circuitry providing an audio input/output capability, a bar codes scanner and/or a keypad and display device.

Temperature sensor 64 provides an input to processor 68. In the preferred embodiment, temperature sensor 64 would be placed in a position so as to provide an ambient temperature reading which can be compared with the temperature reading from one or more tires so as to provide a differential temperature sensing capability.

Turning now to Figure 4, a block diagram representing the receiver, transmitter and communication link are presented. In the preferred embodiment of the present invention, communication link 12 is implemented via the components of the vehicle which constitute electrical ground for the vehicle battery and other electrical systems. Transmitter 22 has signal output 86 referenced to ground 82 isolated from vehicle ground 80. This signal output 86 is connected to vehicle ground 80 which in turn is connected to signal input 88 of receiver 24. Receiver 24 in turn is provided a ground 84 which is also isolated from vehicle ground 80.

In one embodiment of the present invention, vehicle ground 80 comprises such elements as a metallic wheel on which a tire is mounted, the wheel bearings and axle, as well as the axle supports and vehicle frame. In effect, these components, their connections, and/or any gaps between these components, provide an electromagnetic path for which a signal can travel from transmitter 22 to receiver 24. In effect, the receiver and transmitter operate from a common antenna which comprises the vehicle ground. Experimental results indicate that this approach is both a viable and effective method for transferring signals in the 100 KHz to 1 GHz carrier range between transmitter 22 and receiver 24.

In the preferred embodiment, this conductive path would include a vehicle wheel, the wheel bearings and at least one stationary conductive component of the vehicle such as a vehicle axle or the like. By this means, the rotating transmitter/detector unit can communicate a signal to a stationary portion of the

vehicle for either direct or remote detection by the receiver/user interface unit.

As shown in Figure 15, in an alternative embodiment of the present invention, a signal repeater 452 receives a transmitter signal from transmitter 22 via electromagnetic path 450. Repeater 452, in turn, retransmits the transmitter signal to receiver 24 via alternative communications link 454. This alternative communications link could be an RF link, a fiber optic link or a direct connection. Further, the repeater 452 could simply amplify the incoming signal before retransmission, or it could decode the signal before retransmission in the same or in a different format. In addition, the repeater 452 could add an identification signal to the communication to identify the repeater or the tire which was the source of the communication.

In the one embodiment, the repeater 452 decodes the digital data from the transmitter 22 and retransmits the data to the receiver 24 in a trinary format as follows. Turning now to Figure 16, the repeater unit 452 is connected to a source of voltage 460, such as a 12 volt vehicle battery, through a current limiting element, such as resistor 462. In effect, repeater 452 provides a load 468 on non-ideal voltage supply 464. By varying load 468, the repeater 452 can, in turn, vary the voltage 466 to multiple levels such as 12 volts, 9 volts and 6 volts used in the trinary scheme of one embodiment of the present invention. This trinary scheme is used to convey the data to receiver unit 24 which is provided with a suitable decoder, corresponding to the transmission scheme used. The repeater 452 is powered by regulating the voltage 466

down to a level, lower than the lowest level of the multiple voltage levels. The choice of the value of current limiting element or resistor 462 is thus based upon the power consumption of the repeater 452, the
5 varying load values 468 and the magnitude of the supply voltage 460.

Thermistor 64 could optionally be located in, or in close proximity to, repeater 452. The temperature read by a decoding unit in the repeater could be sent to
10 receiver 22 along with the data received from transmitter 24.

Turning now to Figure 5, a schematic representation of the user interface/receiver unit 14 is presented. The heart of this unit is CMOS
15 microprocessor unit 100. This microprocessor operates in conjunction with 32K RAM chip 102, 16K EPROM 104, address decoding chip 106, databus 108 and address bus 110. The microprocessor unit 100 is provided with an audio indicator and driver 112 consisting of buzzer 118
20 and MOS transistor 120. Microprocessor unit 100 is further provided with an LCD display 114 which is capable of displaying various letters, numbers, and symbols to a user.

LCD display 114 communicates with
25 microprocessor unit 100 via databus 108 and control lines 122. Variable resistor 124 provides a brightness control for LCD display 114.

RS232 link driver 126 is also connected to microprocessor unit 100. This RS232 driver comprises transmitter/receiver unit 128 and RS232 DIN connector 130.

5 Microprocessor unit 100 further includes oscillator circuitry 132 for providing the clock signals which drive the microprocessor unit. Further, microprocessor unit 100 is provided with a second oscillator 134 which provides a clock for providing the
10 calendar functions to the microprocessor.

Capacitor 130 connected to microprocessor unit 100 provides a power on reset function such that the operation of the microprocessor is initialized each time the unit is powered up. Capacitor 138 provides static
15 discharge protection for the microprocessor which is advisable given that the microprocessor utilizes CMOS technology.

Terminal 140 is attached to a vehicle terminal which is a logic low voltage when the vehicle headlights
20 are off and is a logic high voltage when the vehicle headlights are on. This high or low voltage is sensed by driver circuitry 146 which is connected to LCD display unit 114 so as to dim the display if the vehicle headlights are on.

25 Power for the unit is provided from the vehicle via vehicle ground 144 and vehicle battery terminal 142. Vehicle ground 144 and battery terminal 142 are fed to isolated self-oscillating power supply 148. Filter 150 provides protection against the
30 emission of electromagnetic interference or more

specifically radio frequency interference which could plague the operation of other components of the vehicle. Further, filter 150 filters the input signal to the power supply. Transformer 152 in conjunction with full
5 wave bridge rectifier 144 and voltage regulators 156 and 158 provide a source of five-volt and nine-volt DC power which is isolated from vehicle ground 144. Lithium battery 160 provides a back up source of power in case the vehicle battery is disconnected.

10 In an alternative embodiment, bridge rectifier 144 could be coupled to vehicle power supply and ground by means of two separate series inductors (one for supply and one for ground). This configurably would provide an isolated ground terminal while filtering R.F.
15 signals from the power supply.

Receiver and decoder module 162 provides the functions of Manchester/FSK decoder 60 from Figure 3. Receiver and decoder 162 is connected to the vehicle ground 164 serving as the primary communication link
20 between the transmitter unit and the receiver. Temperature sensor 64 is connected to microprocessor unit 100 to provide an ambient temperature measurement as described with reference to Figure 3.

The Manchester code format utilized by one
25 embodiment of the present invention is shown in Figures 20(a) and (b). Turning now to Figure 20a, a data frame begins with a synchronization sequence 520 and is followed by three 7-bit words 522. These 7-bit words are followed by a 5-bit word 524 and a "more
30 information" bit. Each data frame is followed by an equal interval of silence as shown in Figure 20b.

Referring again to Figure 20a, the 31 bits of the data frame are assigned as follows:

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B
- 5 (a) Bits #1 through #4 are designated for use as frame synchronization bits that indicate the location of the first information bit, bit #5, through use of a Manchester coding violation in its #1 and #3 positions. Bit #1 is the first bit of the 31 bit frame that is transmitted.
- 10 (b) Bit #5 is the least significant bit (LSB) and is the first information bit transmitted. Bit #31 is the most significant bit (MSB) and is transmitted last within the 31 bit frame.
- 15 (c) Bits #5 through #30 ^{are} ~~is~~ used for information bits and parity bits; these bits ^{are} ~~are~~ parsed into 3 words of 6 information bits and 1 parity bit, and 1 word of 4 information bits with parity bit. The 6 LSB's of each word are designated identification information bits, while the MSB is designated an odd parity bit.
- 20 (d) Bit #31 is designated for use as a "more information" bit; when set to a "1" it indicates that a subsequent unique frame of information exists; this applies to transponders with memory capacities greater than 31 bits (59 bits, for example); a "0" is used in the final frame to indicate that all information ^{frames} ~~frame~~ have been received, and that the next frame will be Frame #1. A "0" is
- 25 also employed in single frame applications to indicate that only one unique frame exists.
- 30 (e) All frames conform to this same frame architecture. Assignment of specific bits for
- B

applications could be performed as follows.
For example, the 59 information bits could be
parsed in the following application:

1250X

5	Word 1	Tire Number
	Word 2	Pressure
	Word 3	Temperature
	Word 4	Report Conditions
	Words 5, 6 and 7	Trailer Serial No.

The allocation of the word-4 report conditions
10 are as follows:

0000 -- Normal status
0001 -- Alarm status
1000 -- Program this tire to be left front tire
1001 -- Program this tire to be right front tire
15 1010 -- Program this tire to be right rear tire
1100 -- Program this tire to be left rear tire

B The time reporting function could be used to indicate
such functions as forthcoming reduced power mode of
operation if a piezo-electric cell were used as a source
20 of power with the optional ^{capacitive} ~~capacitative~~ storage,
programming for additional tires, and further system
checks and procedures.

Error detection is determined through parity
checking and through redundant frame reading as follows.

B (a) Error detection is determined through the use
25 of Odd Parity in bit positions 11, 18, 25, ^{and} 30.
Each parity bit is associated with the 6 bits
that comprise the word immediately preceding
it. A valid word contains an odd number of
30 logic "1's" when the number of occurrences

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within the 6 bit word and the parity value are summed.

5 (b) In order for a frame to be accepted as valid, all parity bits must be in agreement with the information bits contained in the associated word.

(c) In order for a read sequence to be accepted as valid, two consecutive valid frames must be read and must be identical.

10 Turning now to Figure 6, a block diagram of the communications between a plurality of
the detector/transmitter units 10 and the receiver/user
interface unit 114 is shown. In one embodiment of the
present invention, each of the detector/transmitter
15 units 10 ^{corresponds} correspond to a separate tire of a vehicle. In
an alternate embodiment of the present invention, two or
more detector/transmitter units 10 are present in at
least one tire of the vehicle for the purposes of
providing redundant operation. The communication
20 between the various detector/transmitter units 10 and
the receiver 14 is carried out asynchronously in the
form of variable length packets of information. Eight
bits of information in each data packet corresponds to
the sensed pressure and eight bits of information
25 corresponds to the sensed temperature.

In one embodiment of the present invention,
the particular tire that is the source of the
transmission is identified based upon the phase shift
and the signal to noise ratio of the received signal.
30 In an alternative embodiment of the present invention,
the particular tire is identified by a tire

identification pattern sent in the data packets corresponding to that tire.

8 In one embodiment of the present invention, each of the detector/transmitter units 10 ~~are~~ powered by
5 a battery. In this application, a pressure and transmitter data is transmitted from the detector/transmitter 10 to the receiver/user interface 14 at periodic intervals such as one minute or ten minutes. Each of the detector/transmitter units would
10 be given a unique eight bit address corresponding to that particular unit. If a scheduled data transmission were not received from a particular unit after one or more periods of operation, the receiver/user interface unit 14 would detect a possible failure of that unit and
15 could provide an indication to the user via the user interface. In one embodiment of the present invention, this unit failure could be conveyed to a vehicle alarm unit (if the vehicle were not moving) indicative of a possible tire theft in progress.

20 To supplement the periodic transmissions, in the event the sensed temperature or sensed pressure from a particular detector/transmitter unit 10 were beyond a certain range, for instance the pressure was beyond +3 or -3 psi from some nominal setting or the temperature
25 were beyond some temperature threshold, a separate unscheduled data transmission would be initiated by the respective detector/transmitter unit 10 and conveyed to the receiver/user interface 14 indicating this fault. Further, this fault condition again could be relayed to
30 the user via the user interface.

An alternate source of power for the detector/transmitter units 10 could be a piezo-electric element. As the tire rotates during operation of the vehicle, the piezo-electric element could vibrate
5 generating power to the detector/transmitter. In one embodiment, the detector/transmitter unit would only send periodic transmissions while the vehicle were moving above a certain velocity. Further, the receiver/user interface 14 would only expect to receive
10 these periodic transmissions when the vehicle velocity were above a certain threshold as sensed by a transducer connected to the speedometer of the vehicle or from a wheel speed sensor used in conjunction with an anti-lock braking system or in conjunction with a magnetic sensor
15 connected to the vehicle drive shaft or the like.

One with ordinary skill in the art will recognize that there are further options for determining the speed of the vehicle. The present invention should be construed in light of these options. Similarly, when
20 the vehicle is in motion and the detector/transmitter units 10 are powered, if the sensed temperature or sensed pressure violate certain preset conditions, an unscheduled transmission would be initiated from that respective detector/transmitter unit to the
25 receiver/user interface unit 14 as in the application where the detector/transmitter unit 10 is powered by a battery.

In an alternative embodiment of the present invention, the piezo-electrical element could be
30 provided with a capacitive storage element. This capacitive storage element could provide sufficient power to provide power to the sensor for some period of

time, possibly seven days or more, while the wheel is not moving. The sensor/transmitter unit would then operate in a power saving mode, such mode communicated to the receiver unit. During this mode, the transmitter
5 22 would be activated less frequently to avoid excessive drain on the capacitive storage and to provide longer operation while the wheel is stationary.

Turning now to Figure 7, a combination schematic/block diagram of a detector/transmitter unit
10 10 is presented. A detector processor logic array 200 is shown as a series of functional sub-blocks 212 through 236. This processor unit 200 is powered
alternatively ^{alternatively} by battery 201 connected to voltage
regulator/voltage transient protector 212 or by piezo-
15 electric battery eliminator 202. This piezo-electric battery eliminator 202 consists of a piezo-electric element 204 which is connected to weighted arm 206. During operation of the vehicle, the tire of the vehicle on which the detector/transmitter unit is mounted spins,
20 causing motion and vibration which in turn causes motion in weighted arm 206. This excites piezo-electric element 204 which generates power to bridge rectifier 208. The signal from bridge rectifier 208 is in turn filtered by capacitor 210 before it is fed to voltage
25 regulator/voltage transient protector 212. Capacitor 210 further provides storage of accumulated charge for operation when the tire is no longer in motion.

Induction coil 244 is placed so as to provide an inductively coupled communication link between
30 induction coil 244 and a separate, remotely ^{placed} ~~placed~~ coil. This inductive link provides a source of communication between the detector/transmitter unit 10 and a remote

controller for remote controlling and monitoring of the unit. This inductive link 242 is connected to service detector 222 of processor 200 via voltage doubling diodes 241.

5 In the preferred embodiment, this inductive link is operated at carrier frequency of 400 KHz with a CW modulation scheme with a pulse rate of 10 K pulses/sec. A sample baseband waveform 500 is shown in Figure 19. Twenty pulses followed by 3 msec of silence
10 provide synchronization. Four bits of information are transmitted LSB to MSB where a binary "0" is represented by 40 pulses followed by 2ms of silence and a binary "1" is represented by 60 pulses followed by 2ms of silence.

 Referring again to Figure 7, processor 200
15 further comprises programmable logic array 226 EPROM 228 and clock oscillator circuitry 224 connected to external clock circuitry 246. Manchester code generator 232, service code identifier 234, ID code identifier 236 and FSK generator 230 generate the transmitted wave form to
20 be sent over the communications link. As shown in the preferred embodiment in Figure 7, FSK generator 230 is connected via resonant impedance matching network 238 to vehicle ground 240.

 Processor 200 further comprises analog to
25 digital converters 216, 218 and 220. Thermistors 258 and 254 in conjunction with capacitors 256 and 252 are configured so as to provide an R-C time constant which varies with temperature. When thermistor 258 and capacitor 256 are given a step input of voltage, the
30 rate of increase of voltage on line 257 as read by A to D converter 216 as a function of the resistance of

thermistor 258 and thus a function of the temperature of thermistor 258. Optionally, A to D converter 218 reads the voltage on line 253 which is a function of the temperature of thermistor 254.

5 Pressure within a tire is determined based upon a similar RC circuit comprising resistor 250 and capacitive pressure transducer 248. When a step voltage input is applied to this RC network, the rate of increase of the voltage on line 249, as read by A to D
10 converter 220, will be a function of the capacitance of capacitive pressure transducer 248 and thus a function of the pressure to which it is exposed.

 One with ordinary skill in the art will recognize that a wide variety of different pressure
15 transducers and driving circuits could be used. The present options are for illustrative purposes and are not intended to limit the scope of the invention.

 Turning now to Figure 8, a block diagram of the supervisory feature of the detector/transmitter unit
20 10 of the present invention is shown. Detector processor 200 is connected to detector ROM 304 and detector RAM 306. Further, the processor 200 communicates with a remote control device shown over supervisory link 300 via decoder/encoder 302. In the
25 preferred embodiment, supervisory link 300 is implemented by the inductive link described in conjunction with Figure 7. Unique 4-bit patterns initiate the functions of dumping and storing various system parameters including the tire number, transmitter
30 unit ID number, and also including the various pressure and temperature thresholds and nominal values, if

applicable. Further, remote control via the supervisory link may allow the user to change the controller configuration, for example, switch the processor from receiving inputs from one A to D converter or another.

5 In addition, by remote control a test program could be initiated for determining whether or not the sensor or alternately the battery is operating properly.

Moreover, via remote control the user could dump the system ROM or RAM or alternately store additional data in the system RAM. In addition, the remote user could dump additional system information including the vehicle number, the serial number, the production date of the software in the ROM or other system information.

10

15 Turning now to Figure 9A, a diagram showing an object of the present invention is shown. Vehicle 308 is provided with a receiver/user interface unit 14 which communicates with individual tire parameter detector/transmitter units 10 located within each of the tires.

20

Turning now to Figure 9C, a vertical cross section of the detector/transmitter unit 10 of one embodiment of the present invention is shown. This unit is housed in phenolic casing 310 attached to stud rivet 312 which is spot welded to the interior wheel rim wall 314 of a vehicle.

25

Figure 9B presents a more global view of detector/transmitter unit 10 as is connected to wheel rim wall 314 via stud rivet 312. Lips 316 of wheel rim wall 314 are provided for accepting a tire 315. Rivet

30

312 is provided with point 318 as shown in Figure 9A to aid in the penetration welding of the stud rivet 312 to the wheel rim wall 314. The bottom of phenolic casing 310 is provided with slot 320 for accepting stud rivet 312 as shown in Figure 9D and Figure 9F. The top of phenolic casing 310 provides an access hole 322 as shown in Figure 9E for allowing the admission of pressurized gas within the tire. The pressurized gas is filtered by filter 324 before admittance to chamber 326. Chamber 326 is enclosed by capacitive plate 328 which flexes in response to the pressure of the admitted gas. This capacitive plate 328 is supported by spacers 330 above ceramic substrate 332 on which is deposited a conducive coating supplying second capacitive plate 329. This ceramic substrate also supports components 334 which make up the circuitry of detector/transmitter unit.

In this embodiment of the present invention detector 10 is powered by battery 340 which is connected to circuitry 334 via pin 336 in battery connector 338. Antenna connection 342 from the transmitter circuit is conductively attached to stud rivet 312 for conduction with the electromagnetic path.

Turning now to Figure 17, a further embodiment of the present invention is shown. Detector/transmitter 10 is located within the valve cap 472 for the tire stem 476. The cap 472 could be in electromagnetic communication with the wheel rim 474 via spring 470. Alternatively, this cap 472 could be in electromagnetic communication with the wheel rim via a special conductive rubber tire stem. In this case, spring 470 could be eliminated.

Turning now to Figure 10, the matrix key pad 116 from Figure 5 is shown in more detail. The functions of the key pad are described in detail with respect to Figures 14A-F.

5 Figure 11 presents the various control commands to be used in conjunction with the RS232 interface of the receiver/user interface unit 14 presented in Figure 5. Before any command can be issued to the receiver/user interface unit 14, a capital V must
10 be sent followed by the eight character password followed by a carriage return.

 A capital C followed by a carriage return denotes a command which initiates the receiver/user interface unit to reply with the software version and
15 serial number. A capital D followed by 24 additional characters and a carriage return instructs the receiver/user interface unit 14 to program the 24 character data string represented by small d's in Figure 11 as the vehicle identification code such as the VIN
20 number used in North American automobiles.

 If a capital I is sent followed by a data file followed by a carriage return, the data file is transferred to the receiver/user interface unit 14 which contains the addresses and labels for up to 256 tires.
25 If a capital L is sent followed by a two number combination BB followed by a comma and followed by a second two number combination EE and a carriage return, the receiver/user interface responds by listing all of the tire alarms, meaning each of the alarm conditions
30 which occurred from month BB to month EE.

If a capital N is sent followed by eight characters followed by a carriage return, the receiver/user interface 14 responds by storing the eight characters represented by lower case d's as the password for the system. This password serves as a security check for the RS232 link such that only authorized users may access the control commands presented herein.

If a capital O followed by a carriage return is sent, this initiates the receiver/user interface unit 14 to output all stored events including all alarm conditions and their dates. Further, the receiver/user interface unit 14 is instructed to reset its memory of all events.

If a capital P is sent followed by a 1 followed by a two digit number MM followed by a comma followed by a two digit number DD followed by a comma followed by a two digit number YY followed by a carriage return, the receiver/user interface unit 14 programs a new date wherein the two digit number MM is the month, the two digit number DD is the day and the two digit number YY is the year.

If a capital P followed by a 2 followed by a two digit number HH followed by a comma followed by a two digit number MM followed by a carriage return is sent, then the receiver/user interface unit 14 is initiated to enter a programmed time wherein the two digit number HH represents the hour and the two digit number MM represents the minute.

If a capital P followed by a 3 followed by a three digit number WWW followed by a comma followed by

sixteen characters represented by lower case d's in Figure 11 followed by a carriage return is sent, then the receiver/user interface unit 14 is instructed to program a particular tire number and label wherein the first eight characters represented by a lower case d are the tire number and wherein the last eight characters represented by a lower case d are the label.

If a capital R followed by a carriage return is sent, the receiver/user interface unit 14 is instructed to output all events that have occurred that are stored in memory without resetting the memory.

If a capital T is sent followed by a number 1 through 5 followed by a carriage return is sent, then the receiver/user interface unit 14 is instructed to output the time and date if the number sent is 1, is instructed to output all tires and labels if the number sent is 2, is instructed to output the vehicle ID number if the number sent is 3, is instructed to output the log number if the number sent is 4, and is instructed to output the driver number if the number sent is 5.

Turning now to Figure 12, an alternate pressure sensing device which operates based upon piezo-resistance is presented. A vertical cross section of the piezo-resistive pressure sensor is shown in Figure 12A. Piezo-resistive layer 360 is supported by diaphragm 362. Diaphragm 362 is constructed of silicon liquid crystal polymer or any temperature stable flexible plastic which operates over an automotive temperature range. Diaphragm 362 is in turn supported by plastic retainer 364 which has a pressure inlet 366. This pressure inlet allows the admission of pressurized

gas which in turn deforms diaphragm 362 causing the expansion of the surface of piezo-resistive layer 360.

Electrical contact to piezo-resistive layer 360 is made in conjunction with contact pins 368. These contact pins 368 are supported by plastic retainer 364 and are electrically coupled to brass contact 370 as shown in Figure 12B. These brass contacts are diametrically spaced about annular lip 372 of plastic retainer 364. These brass contacts in turn are in electrical contact with silver contacts 374 which are mounted diametrically on diaphragm 362. As shown in Figure 12 or alternatively, the brass contacts 370 are in direct electrical contact with the piezo-resistive layer 360 as shown in Figure 12E. Piezo-resistive layer 360 is constructed of 20% molybdenum disulfide, 40% activated N-type semiconductor and 40% alkyd or silicon binder.

In operation, the increase of pressure at pressure inlet 366 causes an increase in resistance of the piezo-resistive layer as sensed between contact pins 368 as shown in Figure 13. In operation, this resistance can be measured in a variety of ways known to those of ordinary skill in the art and converted into pressure by a linear offset and scaling constant if operated over a sufficiently small range of pressures. Alternatively, the resistance as a function of pressure can be stored in a look-up table format for proper calibration, and a given value of resistance can then be equated with its corresponding pressure based upon this calibration curve.

The programming of the receiver/user interface unit 14 by means of the matrix keyboard unit 116 shown in Figure 10 as well as the operation of the LCD display unit 114 is illustrated by Figures 14A through 14F.

5 When the power is turned on to the vehicle, display one as shown in block 400 is shown on LCD display unit 114. This display 400 presents the model number of the tire pressure monitoring system as well as the version of the software. If this is the first time that the unit has

10 been turned on, meaning that the unit has not been previously programmed, then the unit waits for five seconds as shown on block 404 and proceeds to display two as shown in block 406. If, however, the unit has previously been programmed either by user input or

15 automatically by the system, the software proceeds to point W 402 in Figure 14D.

Display two in block 406 prompts the user to enter the date. The user then enters the date numerically using the numbers of the keypad shown in

20 Figure 10 followed by the enter key as shown in block 408.

The system then responds by presenting display three as shown in block 410. Display three prompts the user to enter the time. The user then enters the time,

25 again using the numeric keys of the keypad shown in Figure 10 followed by the enter key as shown in block 412. The system then responds by presenting display four as shown in block 414 of Figure 14B.

Display four prompts the user to program the

30 tires or to press enter. If the enter key is not pressed after five seconds as shown in block 416, the

system responds by presenting display five as shown in block 418. If, however, the enter key is pressed within the five second interval, the system responds by going to point W as shown in step 420 which corresponds with a similarly denoted point in Figure 14D.

Display five prompts the user to enter the number of tires to program as shown in block 418 at which point the user enters a number between 1 and 256 as shown in block 422 followed by the enter key. The system then responds by presenting display six as shown in block 424 which prompts the user to enter the sensor number and label. The user responds by entering the tire number and a label designation such as left front, right front, left rear, right rear or spare as shown on the keypad presented in Figure 10 followed by the enter key as shown in block 426. If this is the last tire to be programmed, then the program proceeds to point B of Figure 14C. If, however, this is not the last tire to be programmed, the program returns back to block 424 with display six.

Turning now to Figure 14C, point B directs the software to present display seven as shown in block 428. Display seven prompts the user to choose between degrees centigrade or degrees Fahrenheit for temperature displays. The user then enters one for degrees centigrade displays or two for degrees fahrenheit displays followed by the enter key as shown in block 430.

The program then responds by presenting display eight as shown in block 432. Display eight prompts the user to choose between displaying the

pressure in pounds per square inch or kilipascals per gram. The user responds by pressing one if psi are selected or pressing two if kpg are selected followed by the enter key as shown in block 434. The initial programming being then completed, the program then proceeds to point W 402 presented in Figure 14D.

Turning now to Figure 14D, the program begins by determining if any of the tires are in an alarm condition. If no tires are in an alarm condition, the program presents its operational display -- display nine as shown in block 436. This display presents a heading for the system as well as the date and time. It should be noted that the program continually scans for alarm conditions being received as shown by the program returning to point W 402.

If an alarm condition is sensed meaning that either the temperature or the pressure in one of the tires has exceeded preset limits or thresholds, the system responds by flashing the tire alarm display in providing an audio alarm from buzzer 118 presented in Figure 5 as shown in block 438. One such tire alarm display is presented in display 10 shown in block 440 of Figure 14E. For illustrative purposes, the label "left front tire" is shown as well as the particular alarm condition, in this case, low pressure. It should be noted that display ten persists until the clear or problem fixed keys are pressed at which point the program reverts back to point W of Figure 14D. If the left arrow key is pressed, then the program presents display eleven as shown in block 442. This display presents the tire number as well as the temperature and pressure as read for that particular tire. The program

then waits for ten seconds and presents display 12 as shown in block 444. Block 444 prompts the user to enter the driver number and then press enter as shown in block 446. The program then proceeds to present display
5 thirteen as shown in block 446 of Figure 14F. Display thirteen prompts the user to enter the route number and then press the enter key as shown in block 448. The program then proceeds back to display ten of Figure 14E as shown in block 440, the alarm display.

10 The LCD display unit 114 and matrix keypad 116 of receiver/user interface unit 14 of the present invention could be located at various points within the vehicle. The functionality of devices 114 and 116 could be incorporated into existing vehicle display and input
15 units. Further, these devices 114 and 116 could be housed in a separate unit 500 as shown in Figures 18a and 18b. This separate unit could be mounted in such positions as a vehicle dashboard, a vehicle rearview mirror or headliner, a vehicle center console or a
20 vehicle visor. Additional functions and devices could be integrated into this unit 500 such as a radar detector or a vehicle compass.

While the best mode for carrying out the invention has been described in detail, those familiar
25 with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.